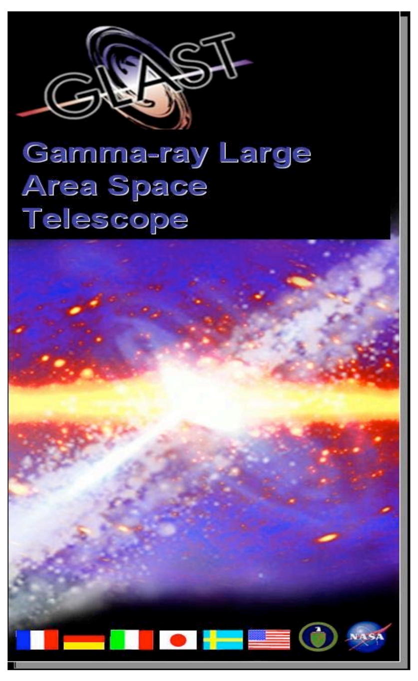

Analysis methods for Milky Way dark matter halo detection

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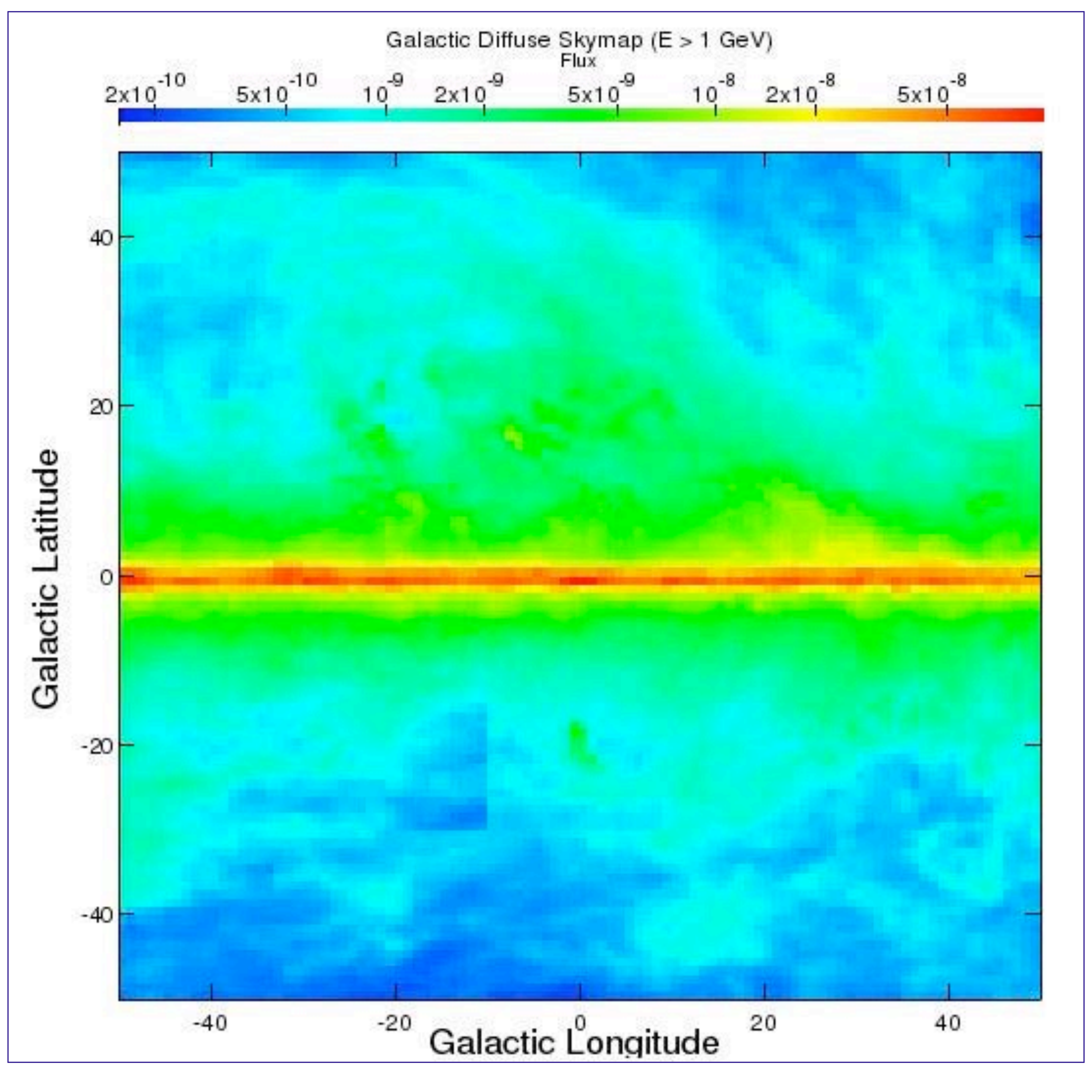
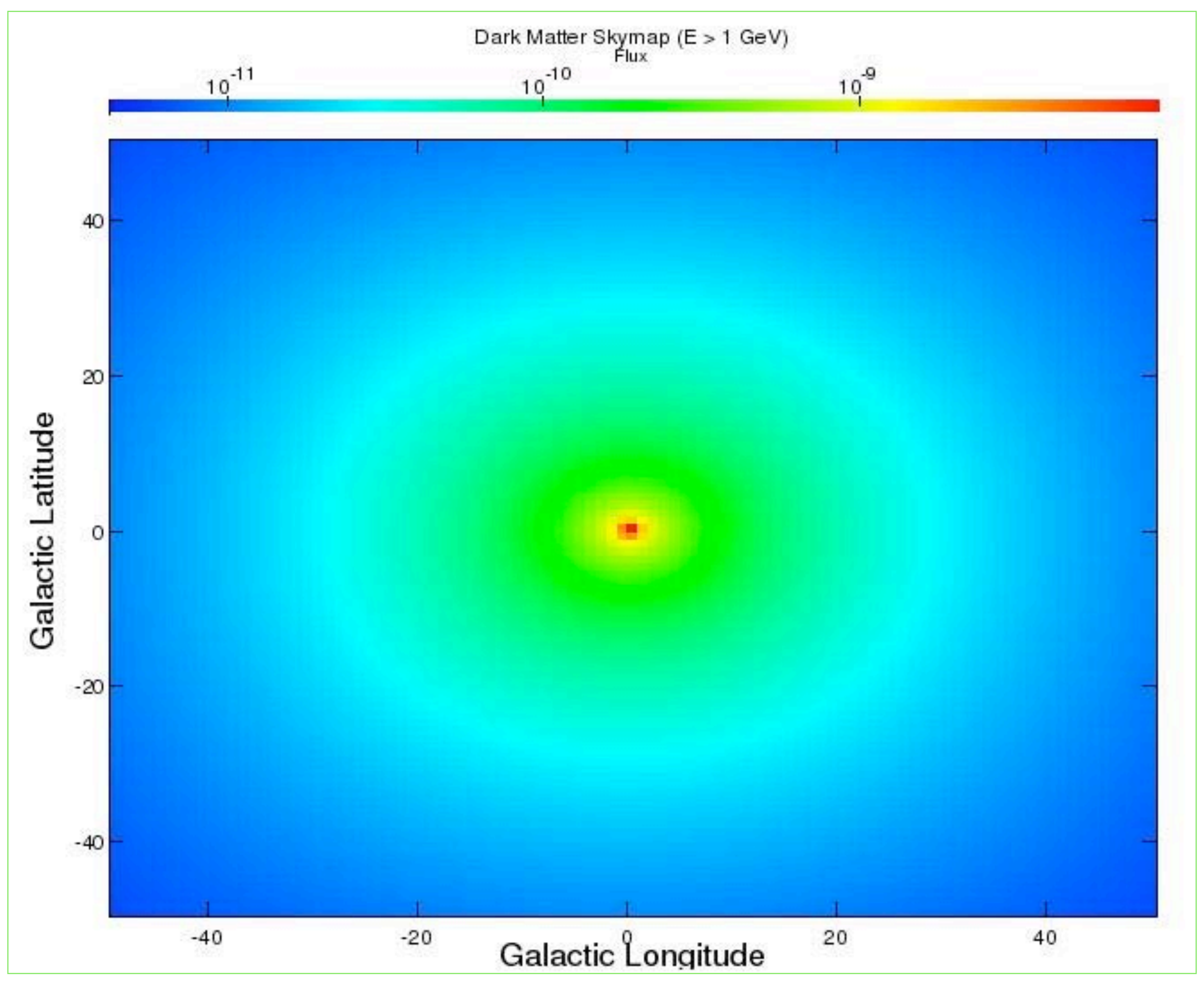
Abstract

We present methods for the analysis of dark matter annihilation in the smooth halo of the Milky Way galaxy. We model the diffuse gamma-ray background using GALPROP, and model the halo using an NFW profile and the gamma-ray spectrum for WIMP pair annihilation. We plan to combine these models with the point source catalog and a simple model for the extragalactic gamma ray background. Using the downhill simplex method to converge on the maximum likelihood value, we can vary key parameters in these models and fit them to the gamma-ray data. Through the use of the Markov Chain Monte Carlo (MCMC) method we can then map out the likelihood as a function of the model parameters to estimate the correlated errors on these parameters.





Dark Matter Skymap

- NFW [6] density profile
- The gamma ray spectra is generated using PYTHIA
- Sample neutralino mass of 160 GeV
- Total flux fixed at 30% of the diffuse total flux
- Dark Matter peaks in both longitude and latitude, making it distinct from the diffuse background
- 100x100 degrees in 0.5 degree bins
- Currently, we are using only continuum gamma rays from neutralinos annihilation to a b-bbar pair because this is the expected dominant annihilation cross section for neutralinos below the top mass

Diffuse Skymap

- The sample used for producing the galactic diffuse was generated with Galprop Version 50 turned to DC2 diffuse emission simulation using a MCMC [5]
- Proton injection spectral index 1.73
- Electron injection spectral index 1.34
- Both spectral indices are derived iteratively from a Markov Chain Monte Carlo procedure
- 100x100 degrees in 0.5 degree bins
- Notice that the diffuse emission is flat in longitude

Physics

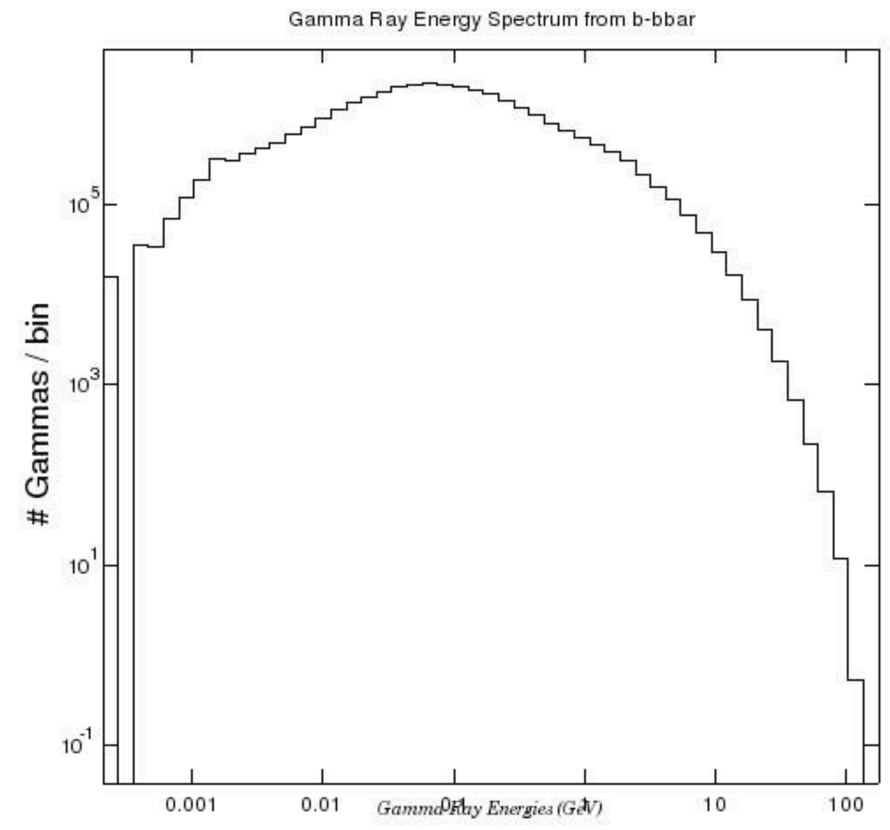
Dark Matter evidence comes primarily from rotation curve data and cluster dynamics. Potential dark matter candidates include axions, black holes, MACHOS, WIMPs, and others[2]. Dark Matter currently makes up 20% of the energy density of the universe.

One of the currently favored models is one in which the WIMP is the lightest supersymmetric particle, called the neutralino. This particle is theorized to be a Majorana particle and this property would allow for indirect detection by GLAST via pair annihilation to q-qbar pairs (continuum), Z gamma, or gamma gamma (lines).

Popular models for the density profile include isothermal [1], NFW[6], Kravtsov[3], and Moore [5]. One parameterization of the density that allows all three to to be included is

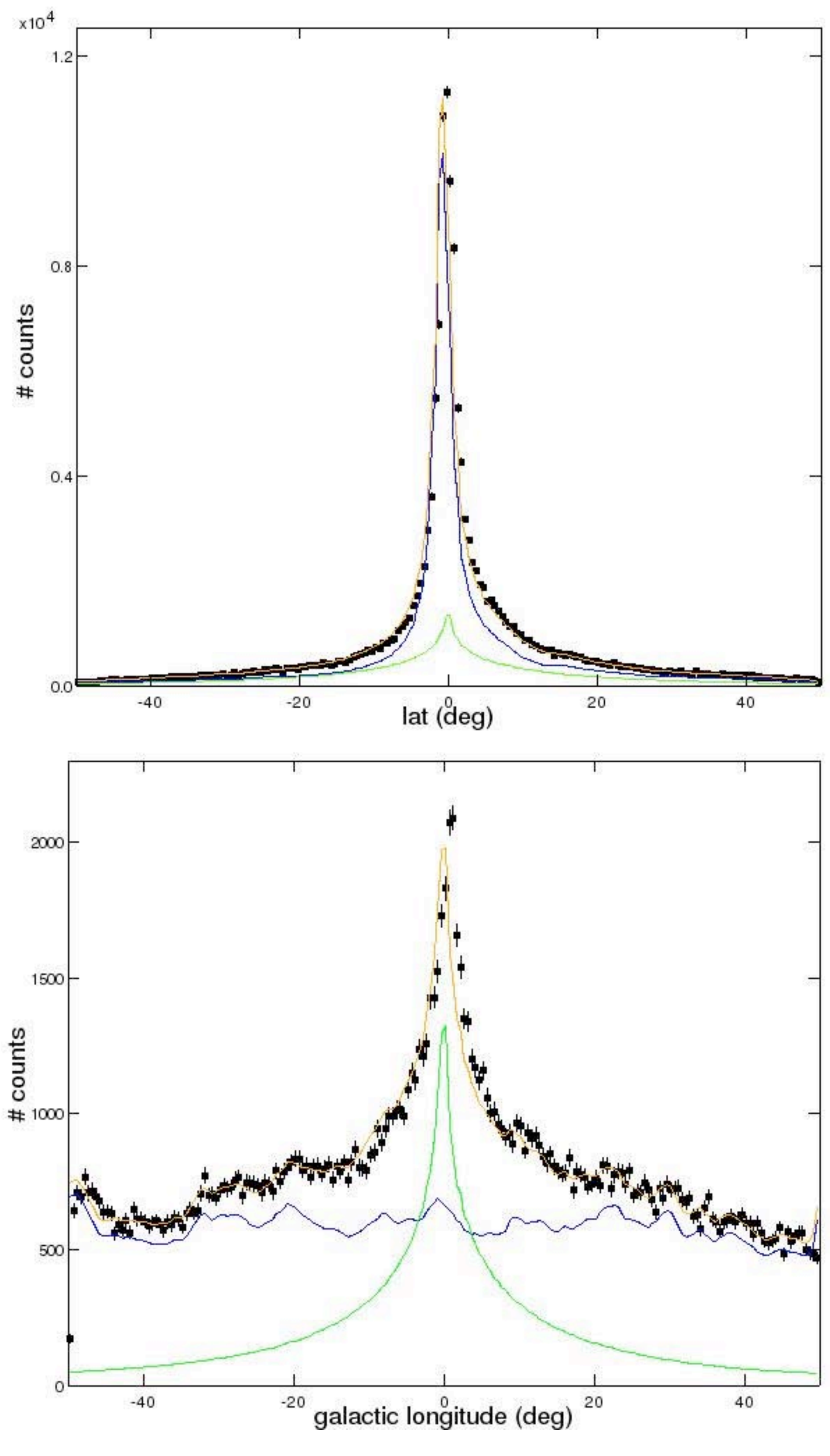
$$\rho(r) = \frac{\rho_0}{(r/R)^{\gamma}[1+(r/R)^{\alpha}]^{(\beta-\gamma)/\alpha}}$$

where R is the characteristic scale radius and ρ_0 is the characteristic density of the halo. Using this parameterization we recover the NFW profile if we set α=1, β=3, γ=1, and R=20 kpc [2].



The plot above shows the gamma ray energy spectra from b-bbar pair

100,000 events generated in PYTHIA with total energy of 320 GeV



These plots contain the fit to *gtobssim* simulated data (black points) for diffuse background (blue), dark matter halo (green) and the sum (orange).

Methods

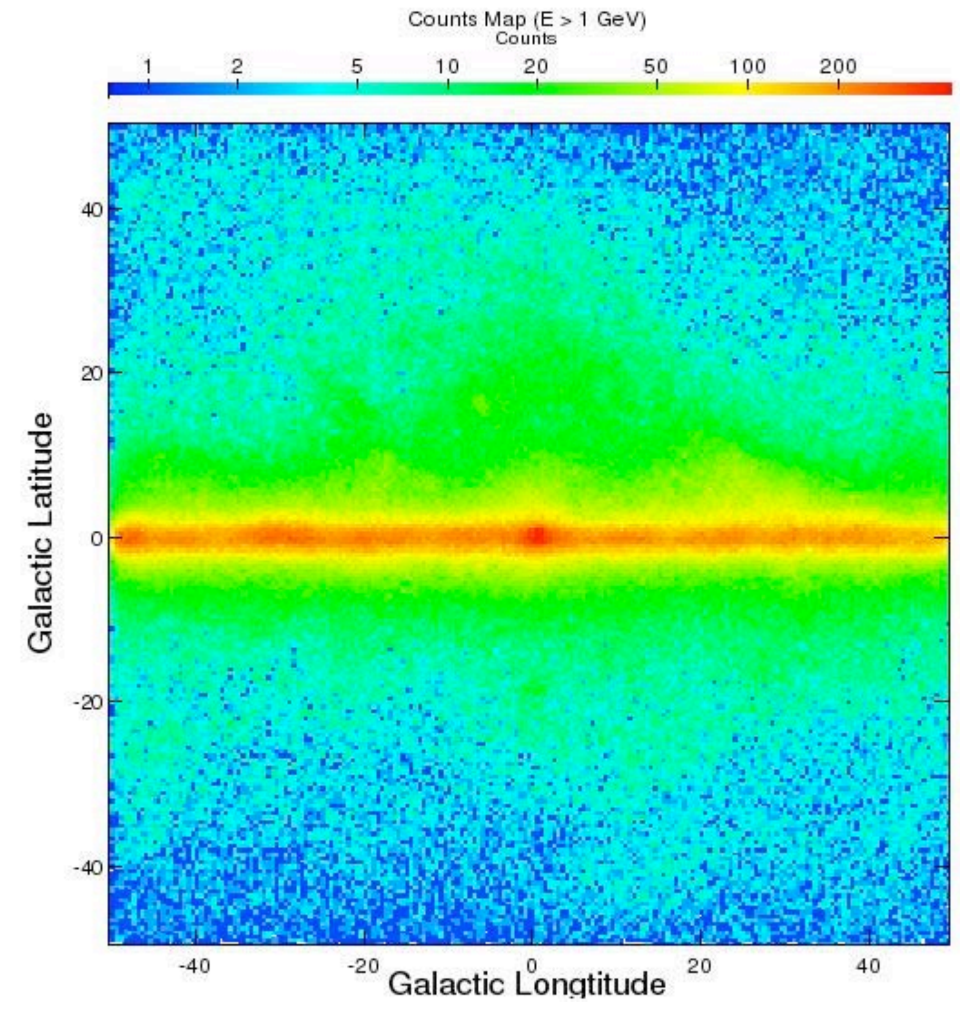
We generated a sample of gamma ray events from the galactic diffuse background skymap and a dark matter halo skymap centered on the galactic center. These events were generated using *gtobssim,* a fast data simulation program, are shown in the counts map to the lower right. Then, using the same skymaps we fit to the simulated counts from *gtobssim* and show the result of the fit in the plot on the left. This fit allows us to check that the relative normalizations of the two skymaps and obtain a maximum likelihood value.

Next, we plan to use the downhill simplex algorithm to vary the model parameters: cross section and neutralino mass for the dark matter halo model; proton injection spectral index and electron injection spectral index for the diffuse model. Using these newly generated models, we will then fit them to our generated counts and obtain a log likelihood value. This process of varying the model parameters would then be repeated until we have mapped out the likelihood profile, L_1, distribution as a function of our model parameters.

We can then obtain the errors on the parameters by noting that on 1/2 unit in log likelihood will give the one sigma errors for that parameter. Also, we can use only the diffuse model to fit the distribution of dark matter plus diffuse, obtaining a second likelihood profile, L_0, and use the likelihood ratio test to create a test statistic distributed as chi-squared [4]:

$$T_s \equiv -2(\ln L_0 - \ln L_1)$$

. With this test statistic we can set limits on detection of a dark matter signal within our sample.



Markov Chain Monte Carlo (MCMC) and Downhill Simplex Method

- The Markov Chain refers to a system of states that change in a stochastic manner, i.e. the probability of future states do not depend on the previous states.
- Each state refers to the set of parameters for the diffuse and the dark matter models
- The down hill simplex method is a minimization algorithm which allows our chain to converge on the maximum likelihood values [7].
- Both the Markov Chain and the downhill simplex algorithms are implemented via Python scripts.

Future Plans

- Currently using only diffuse and dark matter skymaps
  - Plan to expand the analysis to include catalog sources and extragalactic diffuse
- Will start with four initial model parameters:
  - cross section for WIMP annihilation
  - WIMP mass
  - proton injection spectral index for the diffuse model
  - electron injection spectral index for the diffuse model
- Then we will expand to include other model parameters
  - Halo model parameters: α, β, γ, and R
  - Diffuse model parameters: proton and electron indices above the break rigidity
  - Extragalactic Diffuse background flux

References

[1]Bergstrom et. al. Astropart. Phys. 9 (1998) 137 (arXiv:astro-ph/9712318)

[2]Bertone et. al. hep-ph/0404175

[3]Kravtsov et. al. Astrophys. J. 502, 48 (1998). (astro-ph/9708176)

[4] Mattox et. al. Astrophys. J. 461: 396 (1996).

[5]Moore et. al., Mon. Not. Roy. Astron. Soc. 310 (1999) 1147 (astro-ph/9903164)

[6] J.F. Navarro, C.S. Frenk and S.D. White, Astrophys. J. 462 (1996) 563 (astro-ph/9508025)

[7] Press et. al. Numerical recipes in C. 1992. p.460.

[8] Strong A.W., Moskalenko I. V. Astrophys. J. 509:212 (1998)

or <http://galprop.stanford.edu/>